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Structure and functioning of neural networks: the complex network properties of artificial neurons

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Artificial Neural Networks (ANN) are in a non-stopping ascension since the introduction of deep learning and the big data phenomenon, i.e., the growing capacity to collect data. Increasingly deeper and more complex ANNs are being built and achieving impressive practical results in several fields. However, this phenomenon also leads to black-box approaches becoming usual in many applications, as little is known regarding these network's internal functioning. Although these systems can be formalized within statistical mechanics, their emergent dynamics cannot be solved analytically. It is challenging to derive their collective behavior from a knowledge of its neurons, and they are also sensitive to input perturbations (1), a classic characteristic of complex systems. On the other hand, in the past decades, the Complex Network (CN) research has gained strength, which focuses on understanding such systems. CN usually represents real-world phenomena composed of a wide range of elements and interactions, hard to analyze with classical approaches. These properties align with modern ANNs, consisting of large amounts of neurons and synapses with signs of a complex topological organization. It is possible to observe a high correlation between both systems (CNs and ANNs), which is still underexplored. Therefore, this correlation links the present research's proposed ideas. Here we employ CNs for understating the structure and functioning of fully-connected ANNs on vision tasks. We propose a dataset with 124 thousand neural networks to study how they behave under different scenarios. They are employed in a supervised classification setup, using typical construction and training techniques, and considering four vision benchmarks. Each neural network is then approached as a weighted and undirected graph, and centrality measures are computed from its hidden neurons. A high correlation is found between these measures and the network's classification performance. We also propose a new concept of bag-of-neurons (BON), built by grouping neurons with similar local CN characteristics. Six neuron types usually occur in our neural network population, and they share similar properties across different tasks. It is also possible to identify how they are distributed between models with varying classification accuracy. These results suggest the existence of global CN properties governing fully-connected neural network functioning and performance. We are now addressing these properties dynamically (during training) for understanding how they emerge from an initially random neural network. We also explore these concepts for the proposal of new integrative pattern recognition models. A new computer vision method was proposed combining CNs and randomized neural network principles, achieving exceptional performance in different applications such as texture analysis (2) and diagnosis of COVID-19. (3)

Palavras-chave: Neural networks. Complex networks. Computer vision.

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